



R.C.A. INSTITUTES.

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MARCONI INSTITUTE
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Technical Lesson 9

D.C. MOTORS

In our study of electro-magnetic induction it was pointed out that, should electro-magnetic induction cease to be, numerous electrical appliances would be rendered useless. In electric motors electro-magnetic induction is a very important factor and when you have finished this paper you will come to realize just how important it is.

The Direct Current Electric Motor is going to be the topic of discussion, but unless you really understand magnetism and electro-magnetic induction it will be well for you to review these two subjects again in order to refresh your memory on just what takes place about a conductor carrying current also what happens when this conductor is forced through a magnetic field.

The motor is constructed from materials you are already familiar with and it operates according to the laws of magnetism, electro-magnetism and electro-magnetic induction. So you see it is impossible to know (figuratively speaking) just what makes the wheels go around in the operation of a motor unless you are familiar with the above mentioned phenomena.

THE PURPOSE OF THE D.C. MOTOR

First, what is an electric motor and what is its purpose? The motor is a machine so designed and constructed that the electric current applied to it will be changed into mechanical power. Just what does that mean? Suppose we explain it as follows, taking for our explanation a trolley car. Over the track on which the car runs you notice a wire which is stretched from pole to pole. From this wire the trolley car pole collects current, as shown in Figure 1, and conducts it to the electric motor of the car causing the motor armature to revolve. The armature is geared to the wheels of the car. The current, after passing through the motor, is conducted through the wheels and passes into the rails, thence to the ground where it returns to the powerhouse generator. This simple explanation will serve to show you that electrical energy is converted into mechanical energy when the car moves.

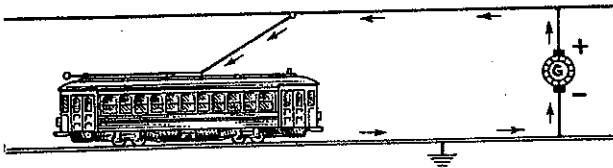


Figure 1

THE PARTS OF A D.C. MOTOR

In the electric motor there are three essential parts. The first part is the field pole which is a piece of soft iron made into a particular shape for the purpose it is to be used. On this field pole is wound a certain number of turns of wire making it an electro-magnet.

The second part known as the armature, is another electro-magnet made so that it can be revolved between the field poles.

The third is a device called a commutator which leads the current into the armature windings.

Referring to Figure 2 we have drawn two electro-magnets and these will be called the field poles, some times referred to as field magnets. This is the first essential part of the motor and when current flows through the windings of these electro-magnets an electro-magnetic field is created, as shown by the dotted lines, which fill the space between the two pole pieces. You already know the general nature of this field from your experiments with the permanent magnets and iron filings.

The armature core of the motor is made up of thin stampings of a good grade of soft iron or steel as shown in Figure 3. A number of these

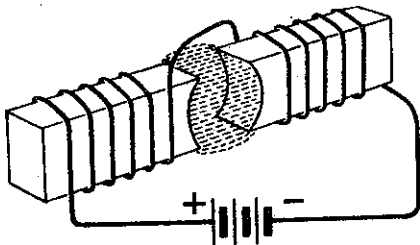


Figure 2



Figure 3

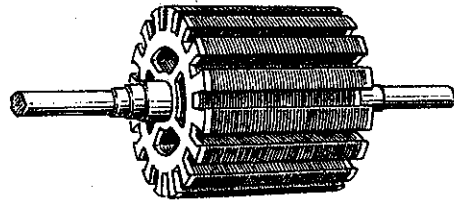


Figure 4

stampings are used to make up the armature core and this core is then called a "laminated" core. Figure 4 will serve to show you how the armature core looks when all these individual discs have been placed, one against the other, making the completed core. The discs are held in place by various methods. In small motors bolts are sometimes employed which run through the discs; in others lock nuts which are threaded to the shaft, and in some makes a collar is shrunk on the shaft holding the discs in place under great pressure.

The slots along the outside of the laminated core carry the coils of wire on the armature, held in place by small pieces of wood which fit into the slots in the core, preventing the coils from being thrown out of the slots by centrifugal force. A cross section of how this is done is shown in Figure 5.

The armature is made up of these laminations to reduce eddy current losses. This loss is brought about when the armature revolves in a magnetic field. The induced currents within the revolving metal

represent a part of the energy being used to operate the motor and does no actual good. In fact an armature so constructed, for example, made of one solid piece of metal would have produced in it eddy currents of such magnitude as to cause the armature to become very hot. This heat represents a large waste of energy.

The armature coils absorb a considerable portion of this heat which causes damage to the insulation and overheats the bearings. It is then advantageous to see that such eddy currents are kept to a minimum.

The losses are very materially reduced by building up the armature of

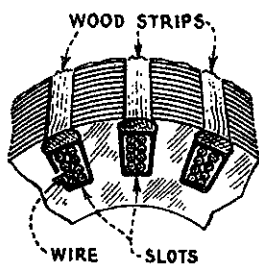


Figure 5

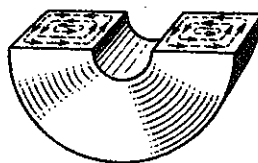


Figure 6

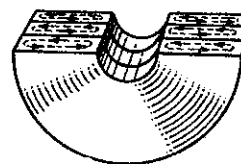


Figure 6A

the thin discs of soft iron and insulating each disc from the other as described. By using laminations the magnetic conductivity of the core is reduced and the circulating eddy currents are confined to each disc, thus preventing these undesirable currents from becoming of such proportions as to heat the armature excessively.

Figure 6A represents an iron core cut in half with the laminations purposely enlarged to show how the eddy currents are confined to each disc. Figure 6 represents a solid iron core showing how the eddy currents move through the entire core.

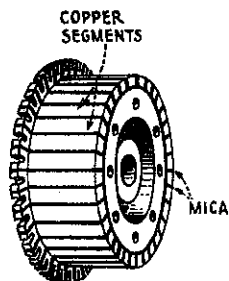


Figure 7A

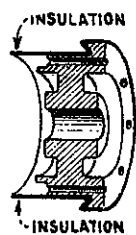


Figure 7B

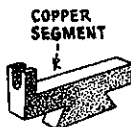


Figure 7C

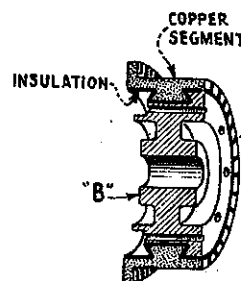


Figure 7E

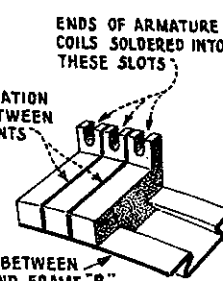


Figure 7F

When the armature coil is passing under one magnetic pole the eddy currents revolve in one direction but as soon as the armature comes under the influence of a magnetic pole of opposite polarity these currents are reversed in direction.

When the armature is revolving at high speed the eddy currents are also rapidly reversed in direction thus causing friction between the molecules of the iron. Friction creates heat which, if allowed to become excessive, not only raises the temperature of the copper

conductors but may cause the insulation of the conductors themselves to burn. This rapid reversal of the molecules creates what is known as "hysteresis losses" and is considered as one of the harmful effects to be avoided in armature design and construction.

The commutator, the next and third essential part of the motor, is a very ingenious device and well worth becoming acquainted with. First we will see how the commutator is constructed. Figures 7A to 7J, inclusive, show the construction of the commutator. Figure 7A is the commutator finished ready to be placed on the shaft. Figure 7B shows locking rings which hold the segments in place.

Figure 7B is one solid piece of iron or steel cast in the shape shown. The commutator requires great care in assembling even though the principle of assembly is simple. The following building up process will give

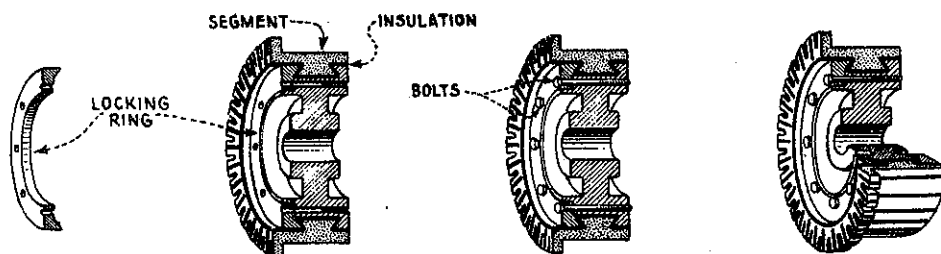


Figure 7D

Figure 7G

Figure 7H

Figure 7J

you the idea of how the parts are assembled. Figure 7B is the part we begin with, the first requirement being to insulate the part as marked for insulation. On this insulated section is then placed the copper segments which are insulated from each other, Figure 7F illustrates the alternate arrangement of mica strips and copper segments. After the required number of segments have been placed on the section, Figure 7B, and insulated perfectly, both from the holder and from each other, as shown in Figure 7F, the locking ring, Figure 7D, is moved into place shown in Figure 7G. The segments are locked into place by tightening the threaded studs which run through the locking ring, into the section, and shown in Figure 7H. Figure 7J illustrates the segments as they would appear with a section cut out of a finished commutator, while Figure 7A is the finished commutator, fitted to the armature shaft ready for connection to the armature windings. The beginnings and ends of the armature coils are brought out and soldered into the slots of the segments as shown in Figure 7F.

This completes the three major parts of the motor. Our next problem is to assemble these parts into a completed machine which is shown in Figure 8, with the various parts marked.

OPERATING PRINCIPLE

As the motor is a machine which converts electrical energy into mechanical energy we must have some means provided to feed the current

into the armature coils. This is accomplished by the use of brushes which rest on the copper segments to which the armature coils are soldered. You see each segment acts as the end of an armature coil. Figure 9 illustrates the brush holder and brushes resting on the commutator through which the E.M.F. is applied to the armature coils.

Now let us consider one armature coil wound on an actual armature. In Figure 10 we can trace the position of this coil from the copper segment

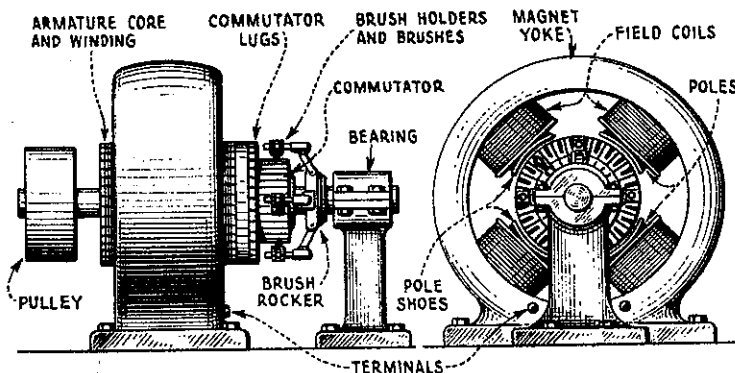


Figure 8

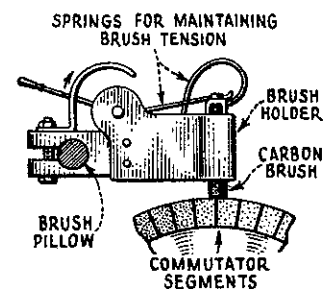


Figure 9

on which the brush rests across the armature core around the back of the core, as illustrated in Figure 11, into the armature slot on the opposite side of the core and finally out where the end is taken to a copper segment of the commutator diametrically opposite the segment from which the coil started. Ordinarily coils are wound in all of the slots but they have been omitted here to enable you to easily trace the position that the one shown occupies on the core. The continual

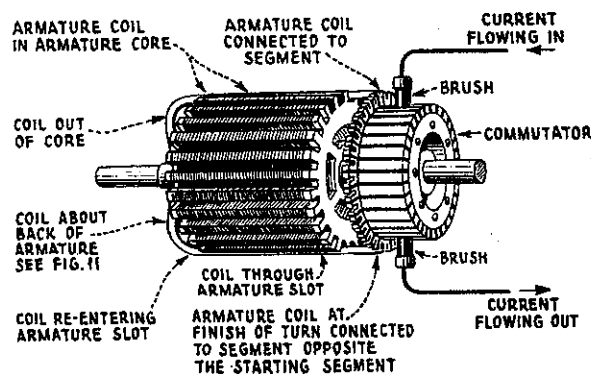


Figure 10

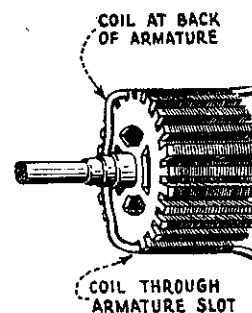


Figure 11

rotation and speed of the motor is dependent upon a great number of coils as you will learn later.

That we may better understand the theory of why this armature revolves when placed in a magnetic field we are going to use only one coil. Figure 12 pictures two field magnets attached to the frame of the

motor. (See also Figure 8.) Note that the magnetic field moves around the iron frame. This is shown to you as it more clearly illustrates the construction of a real motor.

To further aid us in studying the motor action we will use only the field magnets and the space where the armature revolves, as in Figure 13. Here you notice a round circle in the center of the field which represents only one side of an armature coil. Note carefully that the lines of force of the field are moving from the "N" to "S" pole of the magnets in a uniform manner, that is, they appear to be moving in straight lines ending on the "S" magnet very nearly opposite to the point at which they left the "N" magnet. This proves to us that although the armature coil is in the center of the field, the field has not been influenced by the presence of the coil.

This is the natural course a magnetic field assumes; it tends at all times to move in a straight line and should anything happen to divert it from this course it will endeavor to regain its natural state at the expense of whatever attempts to change it.

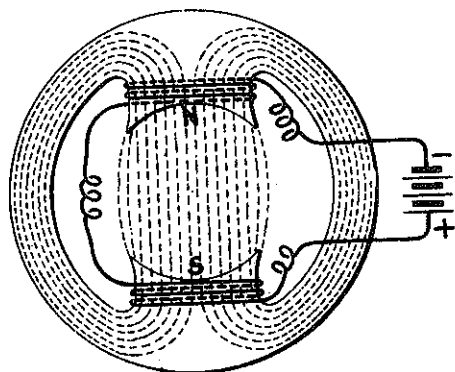


Figure 12

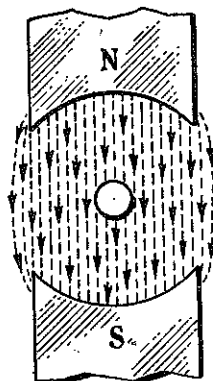


Figure 13

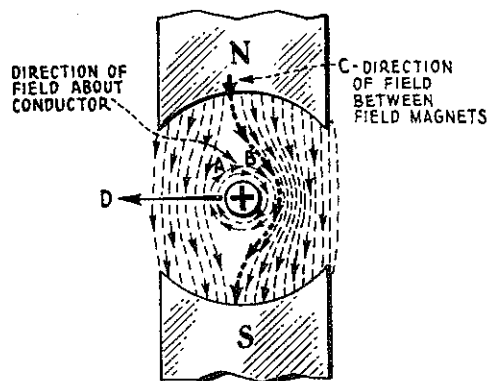


Figure 14

Suppose we find out if that is true. We throw the switch and allow current to pass through the armature coil and observe Figure 14. Now go back and think what happens when a wire carries current. A field springs up at once as shown in Figure 14A. Study Figure 14 and note the wire marked $\oplus$ denoting that the current is moving through the wire away from you with its consequent field indicated by the small arrows. This field of the wire is opposing the field of the magnets on the left side and moving with the field on the right side of the wire.

Now what happens. The field moving from the "N" pole of the magnet moves downward toward the pole marked "S". On the left side of the wire $\oplus$ it meets the field around the wire at point "A" which is moving against or opposing it. This tends to neutralize or weaken the field on this side of the wire.

Looking at the right side, at point "B", the field about the wire is moving in the same direction as the field from pole "N". Let the arrow "C" represent a line of force coming from pole "N"; when it arrives at

point "B" it meets the field of the wire " $\oplus$ ". They have no objection to travelling in the same direction but they must have room to do so, so line of force "C" moves outwards to make room for the field around the wire and, in so doing, all the lines of force in this side of the wire are bunched or crowded in this point, increasing the field strength on the right side of " $\oplus$ ". This bunching of the lines of force of the field increases with the voltage increase which causes the current to rise in the conductor " $\oplus$ ".



Figure 14A

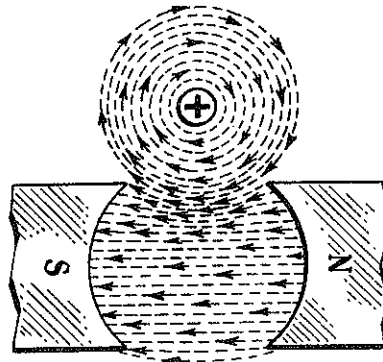


Figure 15

These distorted or bent out lines of force act as taut rubber bands and at any instant tend to straighten themselves. When this happens the conductor " $\oplus$ " will move as indicated by the arrow D.

Figure 15 illustrates the wire nearly forced out of the magnetic field of the pole pieces as the lines of force rapidly restore themselves into straight lines.

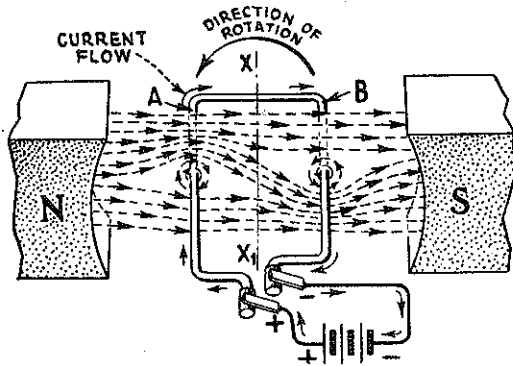


Figure 16

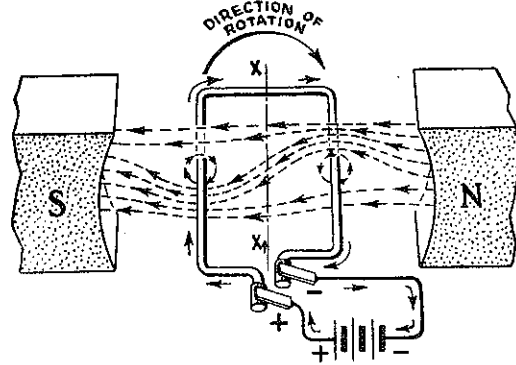


Figure 17

Let us study Figure 16; here we can better see how rotation takes place. You recognize at once the field magnets "N" and "S" but we have drawn a complete loop (armature coil) to further enable you to understand why the armature revolves. This coil is free to revolve on the axis X and X1 which will allow side "A" to move down when side "B" is moving up.

Studying the field as it leaves pole "N" the small arrows show a bunching of lines of force over the top of side "A" of the loop, thus the

magnetic field of the wire has added itself to that of the field magnets making a strong concentration of force above the wire, while underneath the field of the conductor is moving against the field of the magnets thus weakening the field at this point.

On side "B" of the coil the opposite effect is evident which tends to force this half of the coil upward.

This entire coil being free to move on axis X, and X1, rotation takes place. On a practical motor armature there are many coils of wire and the action you have just seen taking place in one coil will also take place in all the coils on the armature. Thus, it can be readily appreciated that when the number of turns on the armature coils and the amount of current flowing therein is increased, either separately or together, the amount of force developed by the armature as it turns upon its axis, is increased.

The motor is designed to produce a turning (or twisting) motion which is called Torque and on this torque depends the work the motor is capable of doing. The magnetic field strength (or flux) times the number of turns of wire on the armature, times the current flowing in the armature coils, gives the torque or turning power of a motor.

For example, in a series motor the field coils are in series with the armature, and if we increase the current flowing the field strength increases so that the torque varies approximately as the square of the current. That is, if we have five amperes flowing to the motor and we increase this to ten amperes then the torque or turning power will be increased nearly four times.

In a shunt motor the field coils are shunted across the armature coils and the field strength, in regards to the varying armature current, is nearly constant. Increasing the armature current twice as much will only double the torque.

It may be necessary to reverse the direction of rotation of a motor. This can be done as follows:

- (1) Reverse the polarity of the magnetic field, or
- (2) Reverse the current flowing through the armature, but
DO NOT REVERSE BOTH FIELD AND ARMATURE CURRENT at the same time
if a reversal of direction is desired.

Refer to Figure 16. With the direction of armature current and field as shown the resulting rotation is anti-clockwise.

In Figure 17 the armature current remains the same as in Figure 16 but the field is reversed. The rotation of the armature is reversed and moves in a clockwise direction.

In Figure 18 the direction of the field is the same as in Figure 16 but the armature current has been reversed causing a clockwise rotation of the armature.

In Figure 19 both the field and armature current have been reversed but the direction remains as in Figure 16.

This proves that to change the direction of rotation of a direct current motor reverse EITHER the FIELD or ARMATURE connections but NEVER reverse both.

THE PURPOSE OF THE COMMUTATOR

The function of the commutator on a motor is to keep the applied current flowing in the armature coils always in the same direction as they come under the magnetic influence of the same field magnets.

Refer to Figure 20 where we have an armature carrying eight coils. Each coil, 1 to 8, is wound on a core and brought out to a commutator segment as shown in Figure 10. To make it as easy as possible for us to study the fundamental action of the commutator we will represent each of the

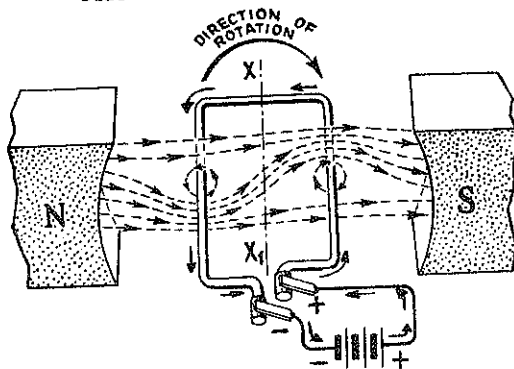


Figure 18

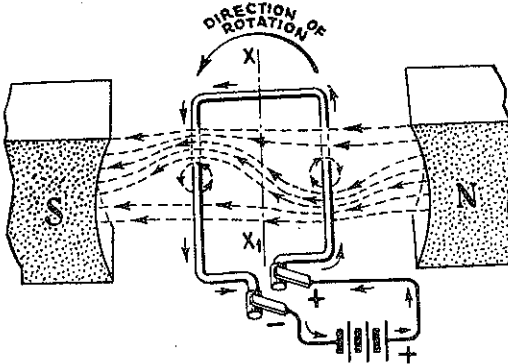


Figure 19

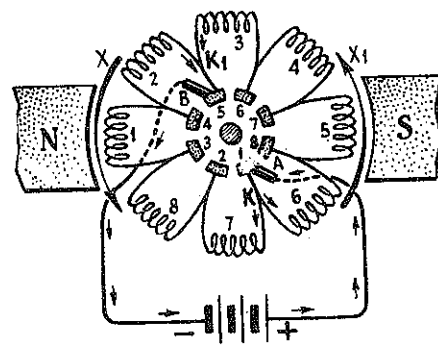


Figure 20

coils as shown in Figure 20. Tracing the current from the battery we see that it flows from the positive side to brush "A", to segment number 1, where it goes into the coil to point "K". At point "K" it divides, part going through coil 7-8-1-2, to point "K1", to segment 5, into brush "B", and returns to the negative side of the battery. Returning to point "K" the other half of the current flows through coils 6-5-4-3 in the opposite direction to point "K1", to segment 5, into brush "B", also returning to the negative side of the battery.

Now let us compare coil 1 with the "A" side of the coil in Figure 16 and coil 5 with the "B" side. The switch is now closed and current is flowing to the brushes on the commutator and coils as described above and as indicated in Figure 20. As coil number 1 comes under the influence of magnet "N" the pressure of the combined field of coil 1 and the magnetic lines of force from pole "N" will force the coil down, indicated by the arrow "X" as shown in Figure 16 side "A". At the same time coil 5 has been forced up, as indicated by arrow "X1", and as shown at "B" side of coil of Figure 16.

As this happens coil 2 has been forced into the field of pole "N" while coil 6 goes under pole "S" and, since the commutator revolves with the armature, segment six will come under and make contact with brush "B"

and segment 2 will make contact with brush "A". The same action now takes place as when coils 1 and 5 were under these poles.

The purpose of the commutator then is to maintain the current flow in each armature coil in the same direction as each coil in turn comes under the influence of the same magnetic pole.

COUNTER ELECTROMOTIVE FORCE

Counter E.M.F., as you learned from Lenz's Law, tends to oppose the applied E.M.F. in the line and its effect is very important in motor operation because it acts as a resistance holding back or limiting the amount of current flowing in the armature coils.

When the armature of a motor revolves in a magnetic field the armature coils cut the lines of force produced by the field magnets exactly the same as though the coils were being driven by mechanical power, as in a generator armature. An electromotive force is induced in the armature coils and this induced E.M.F. is opposite in direction to the applied electromotive force which is furnishing the power. This induced E.M.F. is called the back or counter electromotive force because of its opposition to the applied electromotive force.

The resistance of an armature coil is very low and to place the line voltage, of say 110 volts, on an armature coil when it is not in motion would be the same as connecting a short wire around the terminals of a battery; that is to say, the armature would cause a short-circuit on the 110 volt line.

In our study of the motor, however, we discovered that as soon as an E.M.F. was applied to the commutator segments through the brushes, current moved into the armature coil and the coil at once was forced to move, thus bringing another coil under the brushes where it received an E.M.F., and as quickly was forced away. So you see the applied E.M.F. only has the opportunity to deliver a short impulse to each coil.

In this starting of the motor armature, however, the current taken by each coil is more than is required to drive it. If you connect an ammeter in the circuit it may read 25 amperes at first, but as the armature gains speed, you will see the ammeter needle gradually drop back until, when the armature is revolving at full speed, the meter may only read 4 or 5 amperes.

Now why did the current drop from 25 to 5 amperes? At the start the armature coils were practically short circuited, which allowed an excessive current to flow; but as this excessive current flows in the coils for a very short period of time no damage is done in the case of a small motor. When the coil is forced out of the field the armature turns with it, and as each coil comes under the pole pieces, the same thing occurs, with the armature speed gradually increasing.

As the motor armature begins to revolve its coils act similar to those of a generator, that is, an electromotive force is developed in the

coils, called counter E.M.F. This counter E.M.F. opposes the current which is causing the armature to revolve and by virtue of this opposition, limits the amount of current flowing in the armature. As the speed increases this back or counter E.M.F. becomes greater and greater, allowing less and less current to flow into the coils.

This continues until the full speed is reached when the back E.M.F. may, for instance, reach a voltage of 105 volts. If there is 110 volts applied and 105 "bucking" or opposing it then $110 - 105 = 5$ volts which will be the total E.M.F. forcing current through the armature coils. Suppose the resistance of the armature is one ohm. By Ohm's Law $I = \frac{E}{R}$. $I = 5 \div 1 = 5$ amperes, or the total current flowing in the armature when it is up to full speed. By Ohm's Law figure out what the current flow would be in the armature coils if the armature did not rotate.

$$I = \frac{E}{R} \text{ or } I = \frac{110 \text{ volts}}{1 \text{ ohm}} = 110 \text{ amperes.}$$

This would certainly place a short in the line and cause the fuses to blow, thus protecting the armature coils from burning. Therefore you can realize the importance of C.E.M.F. as applied to the motor; it acts to regulate the current.

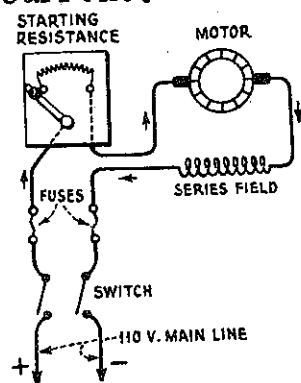


Figure 21

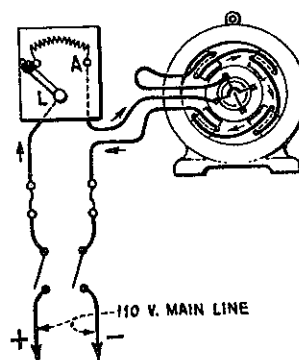


Figure 21A

So far the motor has merely been revolving without driving any machinery. Suppose now the motor is connected to a load; the motor will momentarily slow down and the counter E.M.F. will, at the same time, become less and more current will flow into the armature windings. Now disconnect the load; the speed of the armature increases and so does the counter E.M.F. thus reducing the current flowing into the armature. Any variation in speed of the armature will cause a variation in the counter E.M.F.

This counter E.M.F. then acts to automatically regulate the flow of current into the armature when the load on the motor is varied.

Motors, such as we are going to use in radio, require some means of controlling the E.M.F. applied to the armature at the time of starting the motor, therefore a resistance is placed in the motor line to regulate the current flow to the armature coils. When the normal speed of the motor is reached this resistance is cut out.

This regulating device is called a starting box and is shown in Figures 21 and 21A. Further explanation of starting boxes will be taken up later in this lesson.

TYPES OF MOTORS

There are three types of direct current motors used in radio practice. They are the Series, Shunt, and Compound.

The different types are used according to the work they have to perform.

The series motor, although not found extensively in radio use, will be briefly explained here in order to enlighten you on the field winding connections. This motor is used mostly in electrical hoisting equipment and in electric traction work. It derives its name from the fact that the field coils are connected in series with the armature.

When the switch is closed, placing an E.M.F. on the motor circuit, all the current flowing through the armature circuit must also flow through the field coils. This is clearly shown in the series motor connection in Figure 21. When a load is thrown on a series motor, the speed of the armature decreases, also the counter E.M.F. allowing more current to flow into the field windings. This strengthens the field and decreases the speed. A weak field increases the speed and a strong field decreases the speed. The field coils are wound with a few turns of heavy wire.

THE SHUNT MOTOR

This type of motor is used where a close regulation of speed is required under loads which are constantly varying. The field coils of the shunt motor are wound with many turns of fine wire, thus making the resistance of the field coils high. This allows only a small current to flow of more or less constant value no matter how much current is flowing in the armature circuit. As in the case of the series motor, when the field of a shunt motor is weakened the armature speed increases. The increased speed generates more counter E.M.F. and the armature is at once reduced in speed.

Caution should be exercised in the operation of this type of motor regarding the speed control; the regulation of the speed may be accomplished by the use of a variable resistance in series with the field coil, or by a resistance in series with the armature circuit. The field circuit must not be opened thereby cutting the current off suddenly. If the field circuit suddenly opened the field would become very weak and the motor would operate by the residual magnetism in the field magnets. The armature would increase its speed because sufficient counter E.M.F. could not be generated to reduce the applied E.M.F. and the armature might possibly be torn apart if abnormally high speed was attained. Precautions to guard against an open field will be described later under motor control.

THE COMPOUND MOTOR

The purpose of this type of motor is to obtain a constant speed under all load conditions. It differs from the two types just described

because the field is composed of two sets of windings; a series and a shunt winding. The series winding is wound in such a manner as to oppose the field created by the shunt windings.

The shunt motor is used to a greater extent in radio than the compound type motor. You may not have as much to do with either the series or compound machines as with the shunt wound machine.

MOTOR STARTING BOXES

Controlling the start and stop of electric motors and generators is accomplished by either the manual type of control or the automatic or remote control. The modern radio transmitter is equipped with the latter type so that the operator may start and stop the apparatus from the operating table. The older methods require that the motor generator sets to be started and stopped by manually manipulating the lever of the starting rheostat.

The two methods will be taken up now with diagrams and instructions. The starting resistance of direct current motors, as explained, controls the current flowing in the armature of the machines. A further control of this applied current to the armature is effected by the counter E.M.F. developed by the armature after it begins to rotate

and then the starting resistance may be cut out of the circuit gradually.

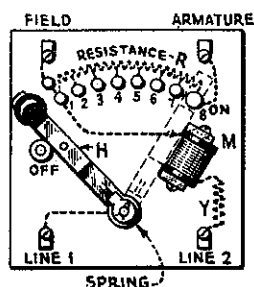


Figure 22

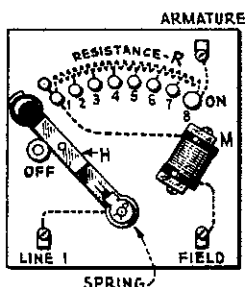


Figure 23

Figure 22 illustrates what is known as a four terminal starting box while Figure 23 is the three terminal box.

The difference between the two starting boxes is the connecting of the holding magnet in the circuit. In Figure 22 the holding magnet is connected in series with the resistance "R" and across the 110 volt circuit as shown. The starting box, Figure 23, has the holding magnet connected in series with the shunt field of the motor.

Figure 24 illustrates the method of connecting a shunt motor to a four terminal starting box. Figure 24A is a schematic diagram of the same motor and box.

Figure 25 shows the proper connections for a compound wound motor with a schematic diagram shown in 25A. When it is desired to start a motor with this type of control the starting arm "H", Figure 23, is moved slowly across the contacts. When the armature is on contact number 1 current flows from line 1 to the starting arm through the arm to resistance contact 1, through the resistance coils 2, 3, 4, 5, 6 and 7 to contact 8 where it is led to the terminal marked armature and from

there to the motor armature. As the arm is slowly moved over the contacts the resistance is gradually cut out and the current slowly increases. When arm "H" reaches the point against the holding magnet "M" and rests on contact 8 all the resistance is out and current flows directly from line 1 to the armature.

The magnet "M" holds the arm "H" which is made of soft iron, in the running position as shown by the dotted arm. This magnet is connected to the first contact and it receives full voltage at first but as the arm moves over the contacts less E.M.F. is impressed across the magnet

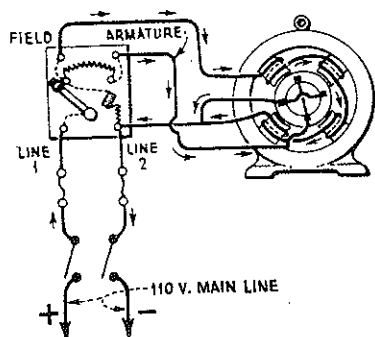


Figure 24

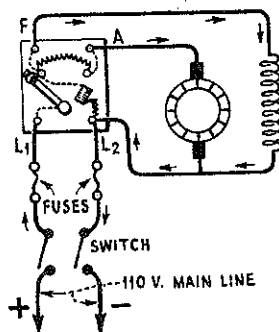


Figure 24A

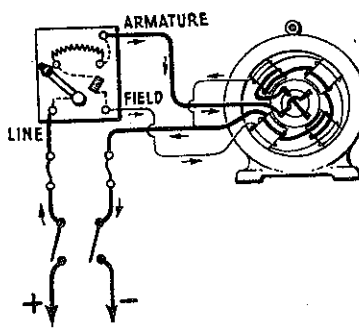


Figure 25

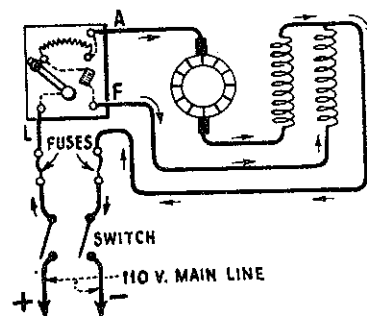


Figure 25A

windings due to the increased resistance through "R" as the arm is moved to full running position. Hence, when the arm is in full running position, just enough current flows through the magnet windings to attract and hold the arm. The resistance protects the magnet winding from heating.

If the field or armature circuit or the line switch is opened for any reason the magnet current is cut off and the arm is pulled back to the "Off" position by a spring located in the shaft supporting the handle.

An automatic or remote control type of starter is shown in Figure 26 and is used where the motor generator is located at some remote point from the Radio operating room in order to prevent the noise of the set from interfering with the signals to be received. This arrangement not only acts as an automatic starter but protects the motor by the functioning of an overload relay in the event of excessive current flow in the armature.

This relay has a magnet winding #18 which is called the tripping magnet. Coil 17 the second magnet of the relay, is the holding magnet. Magnet 18 is in series with the armature on the negative side of the line, and if more than a predetermined number of amperes flow through winding #18 the arm #15 is drawn up by the increased magnetism thus breaking the circuit of the energizing solenoid #5 through the contacts 14 and 15 which is normally in the down position. This arm, when drawn up, makes the contact with contact #16 and coil #17 is then energized being protected by the fixed resistance #20. The holding lever #15 will remain in the up position until the main D.C. line switch is opened or the trouble causing the overload to occur is located and removed.

To start the motor the operator closes switch #19 and switch #21. Relay arm #15 is normally down, bringing contacts 15 and 14 together. Now trace from the positive side of switch #21 around the line to 13, from 13 to protective resistance 12 (which is cut in when the arm 7 has reached its full upward travel) through solenoid winding #5, to contact 14, to relay arm 15, through switch 19, which the operator has just closed, out of 19 to connection 25, where it returns to the negative side of switch 21.

When current flows through this circuit it energizes coil 5 and through electro-magnetic induction arm 7 is drawn upward, being regulated by a dash pot arrangement which permits it to travel at a predetermined speed.

As the plunger arm 7 moves upward the flat portion of the bar 8 makes contact first with contact #1. Current then flows from point 13 to 26,

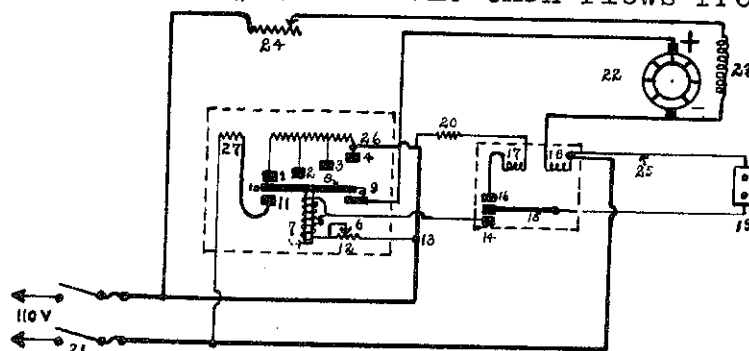


Figure 26

into the resistance units 4, 3, 2 and to contact 1, across arm 8 to the right where it passes through a flexible pig tail. Now to connection #9 to the positive side of the motor armature, through the armature where it returns to the negative side of line switch #21. The motor armature increases its speed as arm 7 rises, and contacts 2 and 3 are cut out. When bar 7 is on contact 4, current flows through the arm 8 and to the motor without passing through any of the starting resistance.

When switch 21 or 19 is opened coil 5 becomes de-energized and arm 7 carrying bar 8 will drop, and contact 10 which is fitted to arm 8 makes contact with contact 11. By tracing this circuit you will find resistance 27 to be connected directly to both brushes of the motor armature; the motor running idle acts as a generator and resistance 27 acts as a load which quickly brings the armature to a stop. This portion of the circuit is called an electro-dynamic brake.

EXAMINATION - LESSON 9

1. Upon what principle does the electric motor operate?
2. What is the function of an electric motor?
3. What are the three essential parts of a motor?
4. How is a motor armature constructed?
5. What is the purpose of the commutator?
6. What is the purpose of the armature?
7. What is meant by the word "torque"?
8. Explain briefly what you know about Counter E.M.F.
9. How is the speed of a shunt motor regulated?
10. Draw a diagram of an automatic motor starter. Explain the purpose of each part.